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EARLY-STAGE TECHNO-ECONOMIC ANALYSIS OF RENOVATING MULTI-APARTMENT BUILDINGS WITH HEAT PUMP SYSTEMS

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Summary

Heat pumps (HPs) can significantly reduce primary energy use compared to conventional fossil-based heating systems such as gas boilers. However, for the application in multi-apartment buildings (MAB), selecting the most suitable, i.e. cost-optimal HP system is challenging because of the multi-dimensional design space. Optimal solutions depend on the project-specific boundary conditions and constraints as well as on the individual optimisation goals (e.g., minimum CO_2 emissions, minimum total annual cost or minimum investment cost). This work introduces an integral planning method for MABs including thermal envelope renovation, HP system topology and HP source as well as on-site PV. A sensitivity analysis is conducted including different types of MABs, with different thermal renovation levels, emission-, distribution-, and generation-systems as well as PV size. Using a spreadsheet-based approach, monthly useful and final energies are calculated, with PV self-consumption, and monthly CO_2 conversion factors accounted for to capture the seasonal variation of the electricity mix. This complements previous studies with a techno-economic analysis focusing in detail on the HP system topology of MAB and considering site-specific details and constraints.

Keywords: techno-economic analysis; heat pump system; CO_2 emissions; building thermal renovation;

Field of application for the findings: Building and system renovation; integration of renewable sources

Addressed audience: Scientific audience, Planners

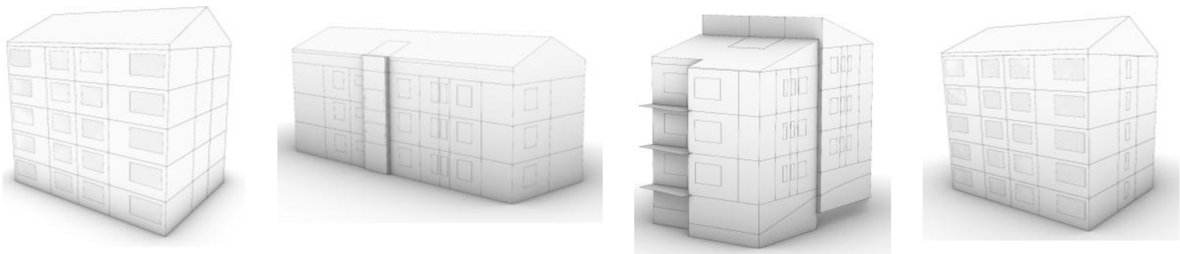
1. Introduction

Heat pumps (HPs) are gaining increasing relevance in multi-apartment buildings (MABs) (Bloess, et al., 2018) and (Bernath, et al., 2019), particularly in the context of renovations (Malevolti, et al., 2024). Accelerating the building renovation rate is essential to meeting the environmental and decarbonisation objectives (European Parliament and Council of the European Union, 2024). As a result, the combination of building thermal renovation and HP system installation is recommended; however, its implementation can be complex, as several elements contribute to the system and an overall optimization is required. HP systems perform best when paired with thermal renovation measures that lower the building space heating (SH) demand, therefore avoiding oversized system and inefficient operation. The HP can provide energy for SH, domestic hot water (DHW), or a combination of the two. When serving both, different distribution configurations of the HP systems can be considered, e.g. 2-pipe system and 2+2-pipe system (Ochs, et al., 2026). The choice of the system influences the pipe thermal losses (and therefore the overall delivered energy) and the temperature required from the HP, which in turn influence the HP performance and the thermal losses. The overall optimal solution also depends on the individual goal, e.g. minimising costs or minimising energy demand (i.e., CO_2 emissions), which can lead to very different design choices. When on-site renewable sources (i.e. PV) are considered, self-consumption becomes relevant. On-site energy production and building and HVAC energy demand vary throughout the year, so the share of demand covered by self-consumption versus grid electricity changes accordingly; moreover, the electricity mix of the grid varies over the course of the year, which can be considered using monthly (rather than annual) CO_2 conversion factors (Ochs & Dermentzis, 2022). An HP system economic optimisation is performed for example in (Vering, et al., 2021) by means of simulations, which highlights the importance of correctly capturing operating costs, as these depend on system control. While detailed dynamic simulations can capture such interactions, they are dataintensive and require not only an extensive modelling and simulation effort but also detailed engineering of each variant. Therefore, a simplified approach is needed to compare different solutions at the early pre-design stage. This study uses a spreadsheet-based approach to investigate different HP system solutions for MABs considering different renovation levels. Generation and distribution of the HP systems are varied to explore performance trade-offs, and the analysis is conducted for four representative MABs, so-called Test Cases, with and without on-site renewable sources and including the effects of self-consumed energy. Monthly CO_2 conversion factors for electricity are used to capture the seasonal mismatch between energy demand and availability of renewable energy, as well as the share of self-consumed on-site generation. Results are assessed from a technical and economic perspective, quantifying CO_2 emissions and cost with respect to a reference case: non-renovated building with new decentral gas boilers). The economic analysis includes investment, installation, maintenance and operative costs over the lifetime of the components. The marginal abatement cost (MAC) can be defined in several ways (Wu, et al., 2023); here, a simplified formulation is adopted and calculated for each variant, indicating the cost required to reduce a given quantity of CO_2 emissions. Such a techno-economic sensitivity analysis covering both building and system has not been presented before and highlights the need for a simplified integral planning tool for the pre-design phase in identifying robust solutions and showing the case sensitivity by comparing four different MABs.

2. Methods

2.1 Test Cases

Four different MABs (A, B, C, and D) with decentralised gas boilers for SH and DHW have been defined as so-called Test Cases. The buildings are shown in Fig. 1 and their key properties are summarised in Tab.1. Test Case D is a detached building with windows in all facades and represents a variation of Test Case A, which is terraced building (attached to neighbouring buildings).



A B C D

Fig. 1: 3D-skecthes of the four MABs considered in the study

Tab. 1: Main properties of the investigated MABs

		A	**B**	**C**	**D**
Treated Floor Area (TFA)	[m^2]	732	593	365	732
Number of floors	[-]	5	3	3	5
Number of apartments per floor	[-]	2	2	3	2
Number of people	[-]	30	16	10	30
Annual DHW demand	[kWh m^{-2}]	21.6	14	13.7	21.6

The buildings were originally constructed between 1960 and 1975 (original state) and underwent a first renovation in the 1990s; hence, the existing case (starting point) has a lower SHD and SHL than the original case (see Tab. 3 below). It is assumed that a replacement of the fossil-based heating system is required. Different combinations of boiler replacement with an HP-based heating system and envelope renovation measures are assessed and compared.

2.2. Parametric Sweep

The goal of the study is to identify the optimal solution as a trade-off between CO_2 savings and total annual cost savings when replacing the gas boiler with a HP-based heating system in the considered MABs. The techno-economic analysis of the four MABS includes a parametric sweep considering variations in the building quality, HP systems topology (i.e. emission, distribution, generation), and the potential of on-site renewable (i.e. PV). The considered variants are listed in Tab. 2. The distribution systems considered are: 4-pipe circulation (4p-C), 2+2-pipe with fresh water station (2+2p-FWS), 2-pipe with heat transfer station (2p-HTS), and 2-pipe with E-boiler (2p-EB) (see e.g. (Ochs, et al., 2026) for details).

Tab. 2: Building, HVAC, and renewable variants

Thermal envelope	Existing, standard renovation, deep renovation
Emission system	Existing radiator, new radiator
Distribution system	4p-C, 2+2-FWS, 2p-HTS, 2p-EB
Type of HP (generation)	Air/Water (A/W HP), Brine/Water (B/W HP)
PV	None, PV on the roof

The SHD and SHL for each building, for the original and existing cases and for the two additional renovation variants, are summarised in Tab. 3.

Tab. 3: Space heating demand (SHD) and space heating load (SHL) of each MAB and renovation variant

		A	**B**	**C**	**D**
Annual SHD [kWh m^{-2}]	Original	164.0	235.9	247.0	239.1
	Existing	134.4	121.4	134.3	204.5
	Standard Renovation	48.5	52.5	51.9	55.1
	Deep Renovation	24.0	22.8	26.1	25.2
SHL [W m^{-2}]	Original	75.7	92.3	99.3	100.5
	Existing	60.4	55.7	61.9	83.6
	Standard Renovation	30.0	27.8	29.6	30.7
	Deep Renovation	18.9	16.3	18.0	17.8

All variants are combined with each other, and results are expressed as additional CO_2 emissions and additional costs relative to the reference case (existing building with new gas boiler with a system efficiency (η) of 85%).

For sake of simplicity, for the cases with PV, the PV area is assumed to be 70% of the roof area, with the other PV properties set to the standard values for monocrystalline PV according to PHPP, see below.

The existing case with old radiator and A/W HP is excluded from the analysis, as it leads to an oversized HP that cannot be installed due to space and noise limitations.

For all the buildings except building B, the flow temperature calculated with old radiators is higher than that with new radiators (assumed to be 55 °C) only in the existing case (see section 2.3 Workflow, below). For the standard and deep renovation levels, the flow temperature with existing radiators is lower, so the installation of new radiators is not considered (economically as well as energetically unfavourable). For building B, the flow temperature with existing radiators in the existing case is lower than 55 °C, due to the larger difference in SHD between the original and the existing case (see Tab. 3).

2.3 Workflow

To perform the whole calculation, including the building thermal envelope, hydronic HP system, renewable sources and monthly calculation, several tools are combined. For the thermal and electric energy balance calculation (and consequently the CO_2 calculation) the following tools are used: PHPP (PHI Passive House Institute, 2026), HP_HS (Ochs, et al., 2025), and PVecon (Ochs & Dermentzis, 2022), as described below. For the economic calculation, the standard PHPP economic sheet (PHeco) is used; in addition, a self-developed sheet is created to calculate the economic aspects of the hydronic system in detail, which extends together with the HP_HS sheet, PHPP's detailed building envelope design by detailed hydronic design options.

2.3.1 Thermal and electric energy performance calculation

The buildings, with their different renovation levels, are implemented in PHPP. Different hydronic systems can be selected, and the required sizing is calculated using the additional tool HP_HS. This allows detailed dimensioning of the distribution system (e.g. pipes and storage) and is linked to the PHPP for calculation of the internal and external distribution losses.

The flow temperature to the radiators is determined in an additional step. For the case of new radiators, the flow temperature is assumed to be 55 °C. Instead for the case of existing radiators, the following approach is used: the room-wise heat load (HL) is calculated for each building and each renovation variant (including the original case). The room with the highest HL is identified as the critical room, and the radiator is sized assuming the original flow and return temperatures (in the original case) of 75/65°C. Verification is required that the critical room does not change across different renovation variants, which follows from the homogenous renovation measures adopted; this may not hold if, for example, insulation is applied to only some external walls rather than the whole envelope. The new flow temperature in the critical room is then calculated from its HL in each renovation variant and the (original) radiator size.

The monthly values are obtained by implementing the tool PVecon in PHPP, which distributes the annual energy on monthly values. It also allows calculation of PV self-consumption, and therefore the electricity required by the grid, which differs between the cases with and without PV.

2.3.2 Equivalent CO_2 emission calculation

To compare the environmental impact of the different energy sources involved (electricity and gas in case of the reference), the energy demands are converted into equivalent CO_2 emissions. For the HP-based cases, annual equivalent CO_2 emissions are calculated as the sum of the monthly values, obtained by multiplying the monthly energy demand from the grid by the corresponding monthly CO_2 emission factors (shown in Tab. 4), according to eq. 1:

$$CO_2 = \sum_{i=1}^{12} W_{from\ grid,i} \cdot f_{CO_2,el,i} \qquad \text{(eq. 1)}$$

For the reference case, emissions are calculated as the sum of a gas contribution (for SH and DHW) and an electricity contribution (for auxiliaries and appliances), according to eq. 2:

$$CO_2 = (Q_{SH} + Q_{DHW}) \cdot \frac{1}{\eta} \cdot f_{CO_2,gas} + \sum_{i=1}^{12} W_{from\ grid,i} \cdot f_{CO_2,el,i} \qquad \text{(eq. 2)}$$

The monthly CO_2 conversion factors for electricity and the annual conversion factor for gas (201 g/kWh) are taken from the Austrian guideline OIB Guideline 6 and reported in Tab. 4.

Tab. 4: Monthly CO_2-equivalent conversion factors in g/kWh for electricity from OIB Guideline 6: 2025

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El	118	105	96	58	10	13	47	37	69	97	96	109

Results are presented as additional CO_2 emissions compared to the reference case. They are defined as the difference between the CO_2 emissions of the considered case and those of the reference case (see eq. 3).

$$\Delta CO_2 = CO_{2,\ considered\ case} - CO_{2,\ reference\ case} \qquad \text{(eq. 3)}$$

2.3.3 Economic calculation

The economic assessment relies on cost functions defined for the thermal renovation measures, HVAC components and the renewable energy systems (PV). For each component, the initial cost (i.e. investment and installation) is converted into an annual cost (AIC) using its service life N and an interest rate of r = 3%. The total investment and installation cost (IC) and annual investment and installation costs (AIC) are then obtained by summing the values of all components. The total annual cost (TAC) is then obtained by summing the AIC with the annual maintenance of each component and the operating costs, covering gas and/or electricity consumption.

All the results are provided as additional costs compared to the reference case, defined as the difference between the considered case and the reference case, in line with the additional CO_2 emissions. This is shown in eq. 4 for TAC as an example, but the same definition applies to ΔIC. According to the additional CO_2 emission, the cost-related optimal solution is therefore the one with the minimum.

$$\Delta TAC = TAC_{considered\ case} - TAC_{reference\ case} \quad \text{(eq. 4)}$$

Moreover, the ratio between additional costs and additional CO_2 emission, the so-called marginal abatement cost (MAC) is calculated (eq. 5):

$$MAC = \frac{-\Delta TAC}{\Delta CO_2} \quad \text{(eq. 5)}$$

An electricity price of 0.32 €/kWh and a gas price of 0.13 €/kWh (E-Control, 2026) are assumed for the annual operating costs. Both prices are treated as constant over the year. No PV payback price is considered.

Cost assumptions for the envelope measures, HVAC components, and PV system are given in Tab. 5, Tab. 6, and Tab. 7, respectively.

Tab. 5: Economic assumptions for the renovation of the thermal envelope (Ochs, et al., 2025)

Building element	Investment and installation	Service life [y]
Scaffolding	$127{,}03 \cdot TFA^{-0{,}32}$ € m_{TFA}^{-2}	-
Extern wall insulation	166,58 € $m_{External\ wall}^{-2}$ + 482,90 € $m_{Insulation}^{-1}$ $m_{External\ wall}^{-2}$	40
Roof insulation	337 € m_{Roof}^{-2}	40
Floor insulation	125 € m_{Floor}^{-2}	40
Basement ceiling insulation	272,80 € $m_{Basement\ ceiling}^{-2}$ + 482,90 € $m_{Insulation}^{-1}$ $m_{Basement\ ceiling}^{-2}$	40
3 pane window	795 € m_{Window}^{-2}	30
Very good 3 pane window	825 € m_{Window}^{-2}	30
Window weatherstripping	42 €/window	10
Improved airtightness	3 € m_{TFA}^{-2}	30
Improved airtightness (EnerPhit level)	5 € m_{TFA}^{-2}	30
Extract air system	46 € m_{TFA}^{-2}	30
MVHR	117 € m_{TFA}^{-2} (additionally: 100 €/apartment/year for maintenance)	30

Tab. 6: Economic assumptions for the HVAC components (Ochs, et al., 2025)

	Investment and installation	Maintenance	Service life [y]
Radiator	80 € m_{TFA}^{-2}	0	30
Storage	20.5 € l^{-1}	0.5€ l^{-1} a^{-1}	30
Air/water HP	$4310 \cdot P[kW_{th}]^{0.6177}$ €	14 € kW^{-1}	15
Brine/water HP	$491.5 \cdot P[kW_{th}]^{1.046}$ €	14 € kW^{-1}	15
Borehole heat exchanger	1000+1667 € kW^{-1}_{th}	0	40
Pipe	1.22 € m^{-1} mm^{-1}	0	30
Pipe insulation	1.06 € m^{-1} mm^{-1}	0	30

Pump	0.41 € l^{-1} s^{-1}	0.006€ l^{-1} s^{-1} a^{-1}	15
Fresh water station (decentral)	3250 €/System	0	25
Heat transfer station (decentral)	3500 €/System	0	25
Fresh water module (central)	10000 €/System	0	25
Electric boiler	1100 €/System	0	10
Gas boiler	6000 €/System	2% of capital cost	20

Tab. 7: Economic assumptions for the PV and battery system (Venturi, et al., 2026)

	Investment and installation	**Maintenance**	**Service life [y]**
PV (roof)	950 € kWp^{-1}	8.4 € kWp^{-1} a^{-1}	25
Inverter	175 € kWp^{-1}	1 € kWp^{-1} a^{-1}	8
Battery	340 € kWh^{-1}	6 € kWh^{-1} a^{-1}	10

3. Results and Discussion

Detailed results for Test Case A are shown and then the deviations from the other test cases are discussed. Results without PV are presented first, followed by results with PV. A comparison within the test cases follows, with a focus on Test Case B, which shows markedly different trends. Finally, the resulting electric peak power requirements are discussed.

3.1 Techno-economic results for Test Case A without PV

Fig. 2 shows the total electricity for SH, DHW, auxiliaries and appliances. The results are shown for the A/W HP (left) and B/W HP (right), for all the combinations of thermal quality of the building envelope, radiator type and hydronic system. Renovation is the most relevant measure to effectively reduce the electricity demand. In all renovation variants, the 2+2p-FWS system achieves the minimum electricity demand, while the system with 2p-EB shows the highest demand. The wrong choice of the SH and DHW heating system can compromise the positive effect of thermal renovation: in the case of deep renovation (annual SHD of 24 kWh m^{-2} with 2p-EB, the electricity demand is higher than in the case with standard renovation (49 kWh m^{-2}) combined with any of the other hydronic systems. This holds true for both heat pump sources. The influence of flow temperature (i.e. new vs. old radiator for the existing building with B/W HP) can be clearly seen in the electricity demand, too (e.g. 80 kWh m^{-2} vs. 96 kWh m^{-2} with 2+2-FWS hydronic system). The B/W HP also shows a relevant electricity reduction compared to the A/W HP, only for the existing building.

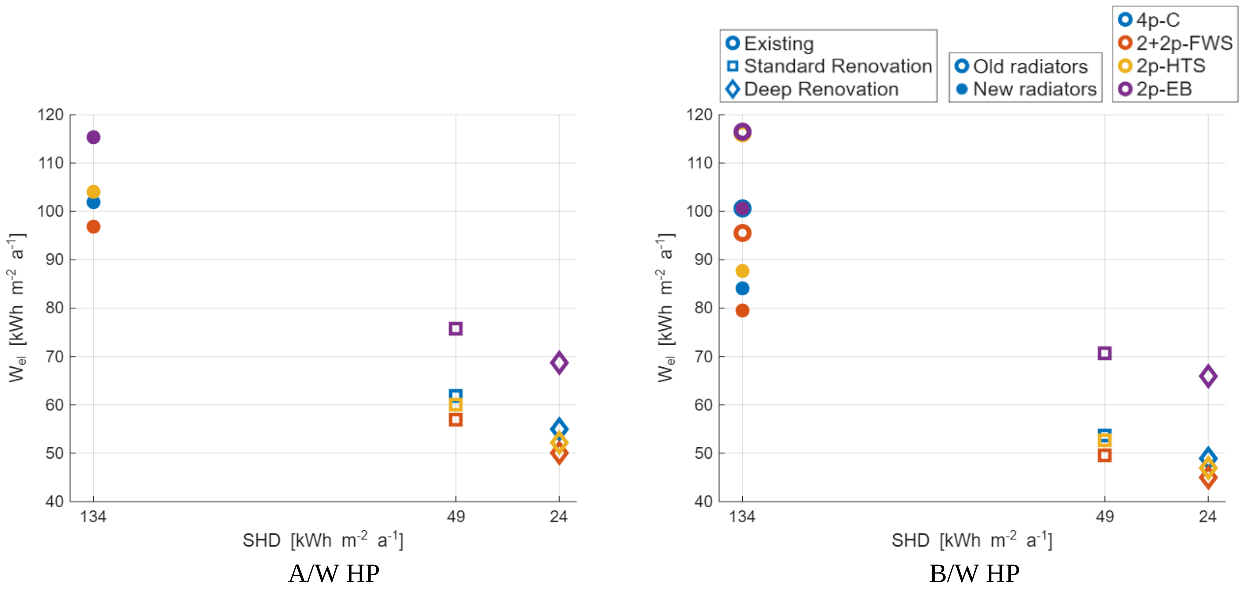


Fig. 2: Electricity required for different combinations of thermal renovation (different symbols), radiator (empty and full symbols), and hydronic systems (different colours) with an air/water HP (left) and with a brine/water HP (right)

The investment (including installation) costs and the additional CO_2 emissions compared to the reference case are shown in Fig. 3. All HP-based cases lead to CO_2 savings (i.e. negative additional CO_2 emissions). The renovation of the thermal envelope has the greatest influence on the investment costs, requiring a large upfront investment at the beginning of the project. This could represent a limit in practice and rule out some otherwise optimal system combinations, even where they minimise CO_2 or life-cycle cost. The B/W HP has higher costs than the A/W HP, but the smaller capacity of the HP in case of the deep renovations leads to overall similar costs.

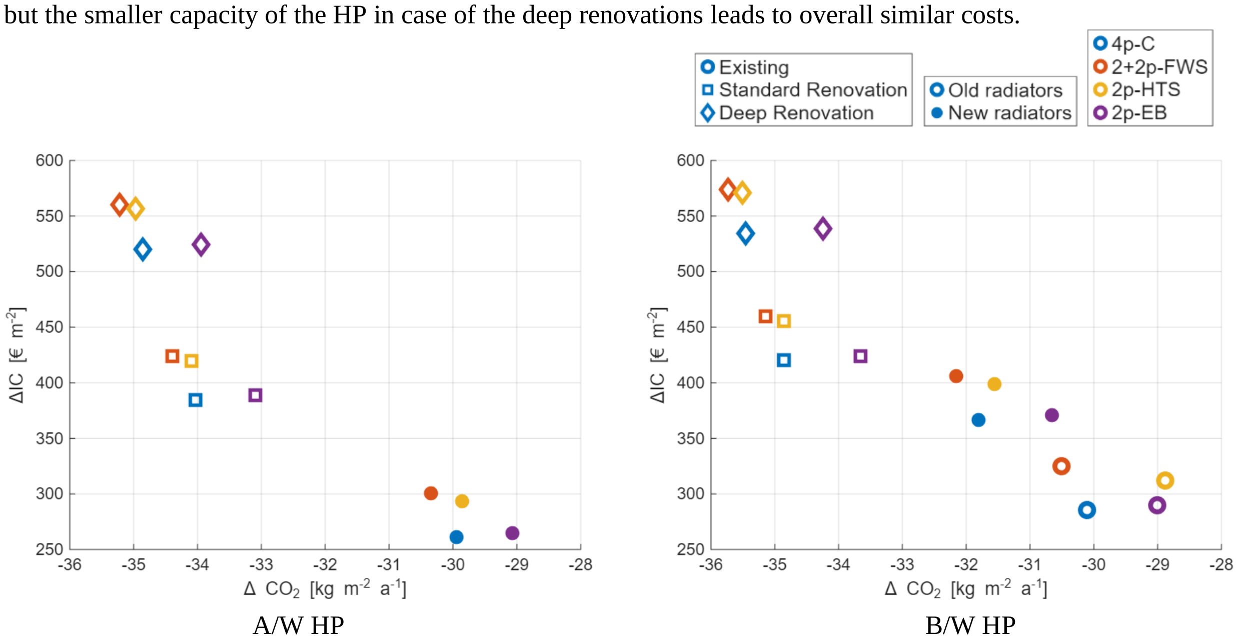


Fig. 3: Additional investment (including installation) costs vs. additional CO_2 emissions compared to the reference case

The additional annual investment costs show similar trends to the additional investment costs, with values ranging between 12 € m^{-2} and 27 € m^{-2}. However, the differences between buildings with different SHD are reduced due to the longer service lifetime of the thermal envelope elements compared to the elements of the hydronic system.

The additional annual investment costs are then summed with the operative costs to calculate the additional TAC, which are presented in Fig. 4. The operative costs have a strong influence in particular in case of the existing building, which shows the highest total annual costs. The building with standard renovation has the lowest total annual costs (an exception are the cases with the 2p-EB). A Pareto front representing the optimal solutions from the techno-economic analysis can be observed in the bottom-left region of the plots.

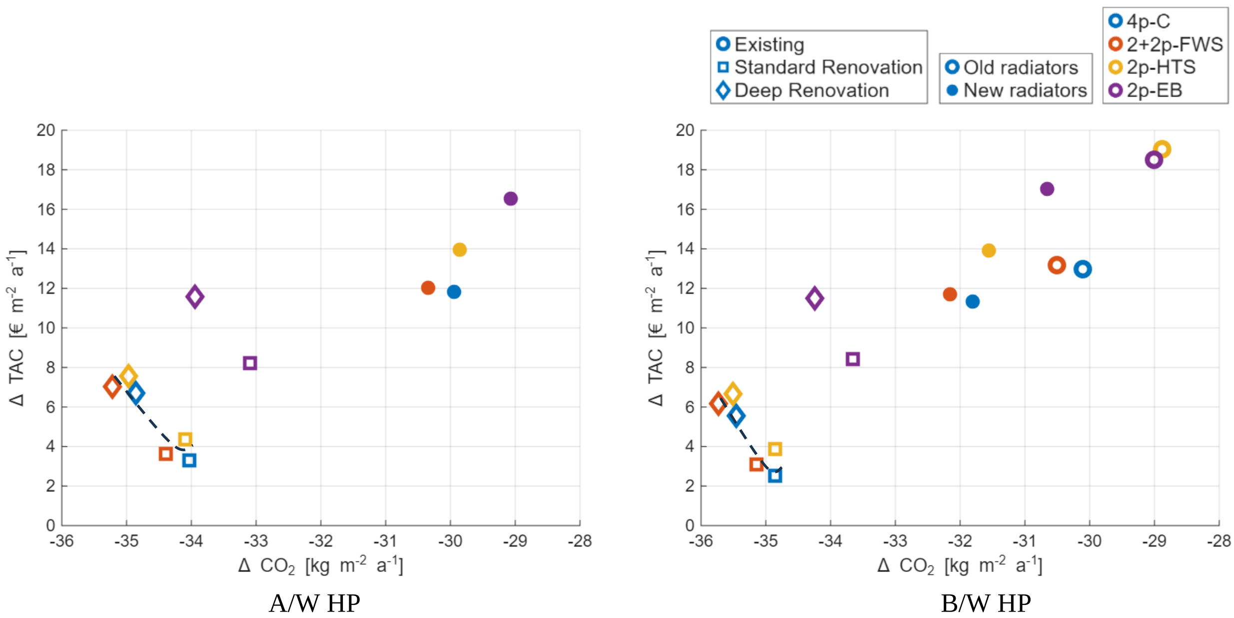


Fig. 4: Additional total annual costs vs. additional CO_2 emissions compared to the reference case with Pareto Front (dashed line)

The marginal abatement costs (Fig. 5) range from -0.01 € kg_{CO2}^{-1} to 0.66 € kg_{CO2}^{-1} and show a trend comparable to the additional TAC. The cases without thermal renovation are characterized by the lowest reduction of CO_2 emissions and the highest TAC and MAC. The cases with e-boiler lead to higher MACs compared to any other case of hydronic system (except the case with existing building with 2p-HTS and old radiator).

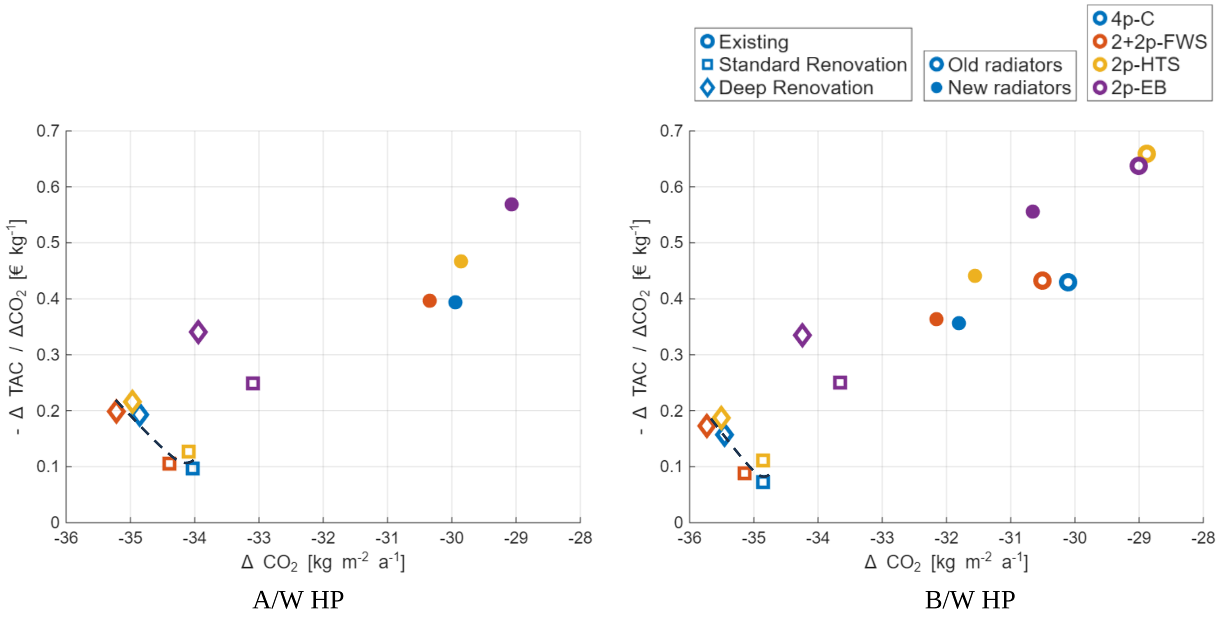


Fig. 5: Marginal abatement costs vs. additional CO_2 emissions compared to the reference case with Pareto Front (dashed line)

3.2 Impact of PV integration on Test Case A

Results including the cases with on-site renewable system (PV) are shown in Fig. 6 and Fig. 7. By covering part of the electricity demand on-site, PV reduces the amount of electricity bought from the grid, which increases CO_2 savings compared to the same cases without PV. PV increases the investment, and maintenance costs, and leads to significantly reduced operative costs, which play the major role: the TAC overall decrease, making a PV solution always economically more convenient than the case without PV. The combination of standard renovation, old radiators, 4p-C, B/W HP and PV results in lower total annualized costs than the reference case.

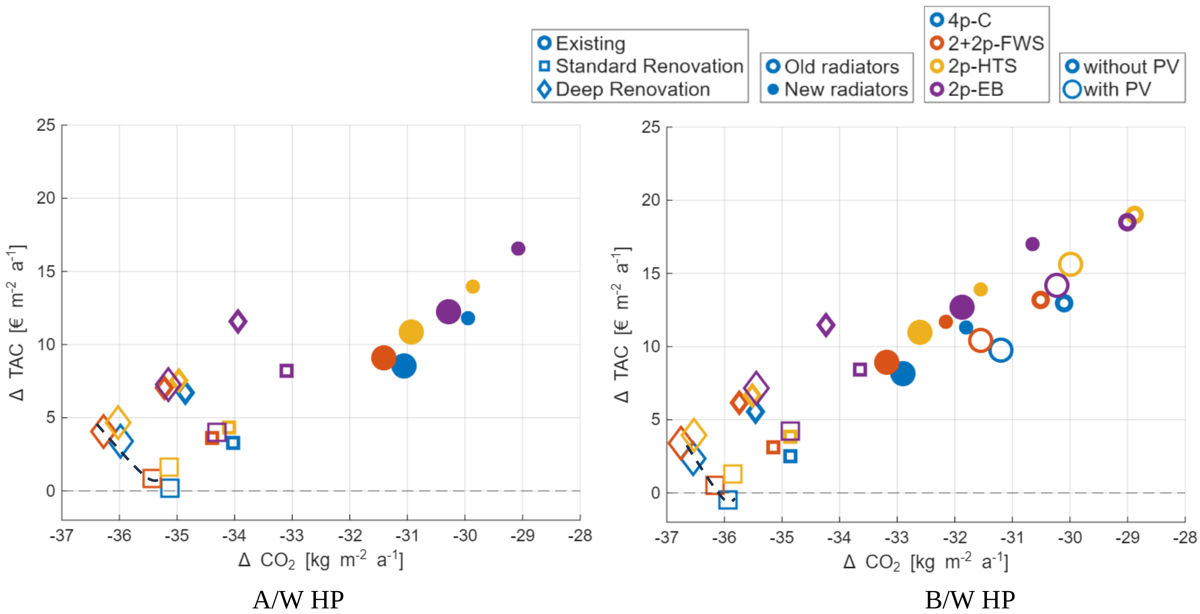


Fig. 6: Additional total annual costs vs. additional CO_2 emissions compared to the reference case, Test Case A including the cases with PV; with Pareto Front (dashed line)

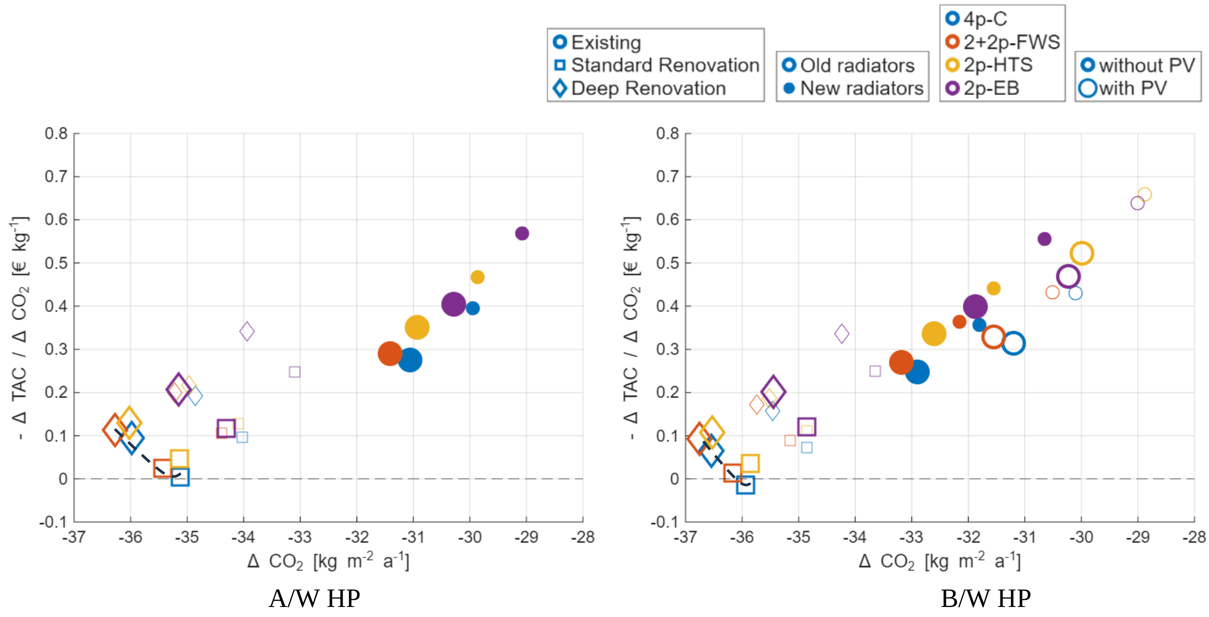


Fig. 7: Marginal abatement costs vs. additional CO_2 emissions compared to the reference case, Test Case A including the cases with PV; with Pareto Front (dashed line)

3.3 Results for Test Case B

Fig. 8 shows the additional TAC for Test Case B, which relevantly differs from Test Case A (Fig. 4): here, costs increase with improved thermal envelope, and the Pareto front includes all thermal envelope qualities, including the existing building and both the 2+2p-FWS and the 4p-C systems. This difference is explained by the ratio between thermal envelope area and treated floor area. Building B has a higher ratio than building A, which leads to higher AIC per treated floor area and higher thermal losses per treated floor area. As a result, while the ranking with respect to the hydronic systems is similar to Test Case A, the ranking with respect to the thermal renovations changes. It is noteworthy that this also depends on the difference in SHD between the renovation variants. Adding PV leads to both reduced TAC and CO_2 emissions, as in Test Case A.

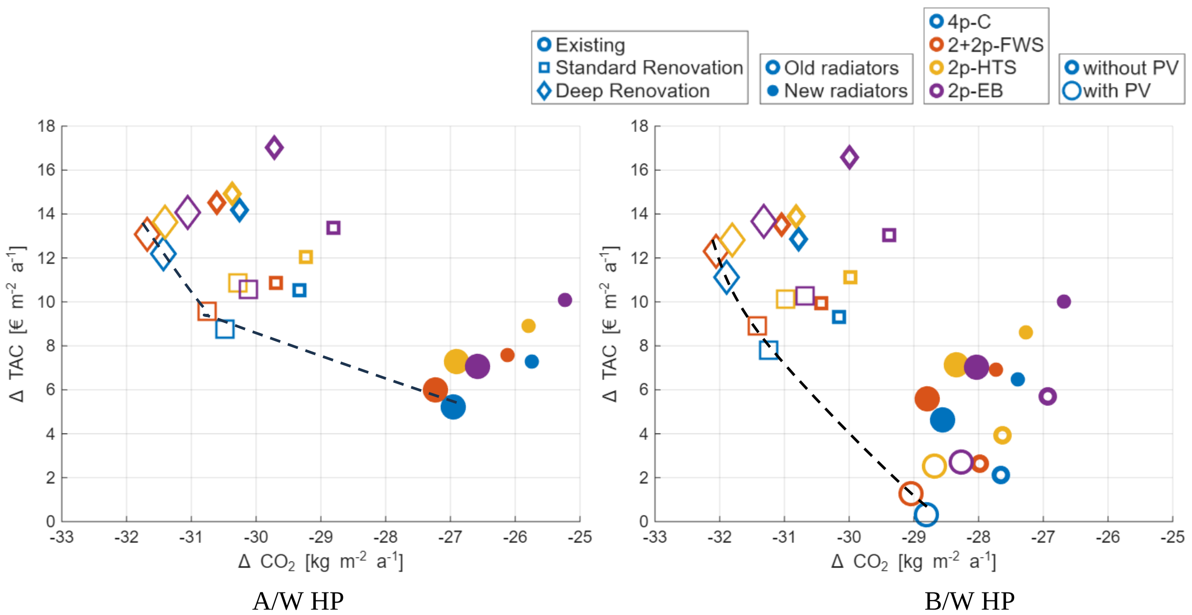


Fig. 8: Additional total annual costs vs. additional CO_2 emissions compared to the reference case, Test Case B including the cases with PV; with Pareto Front (dashed line)

3.4 Comparison of techno-economic results within the Test Cases

The comparison within the test cases is presented in Fig. 9 and Fig. 10 (showing TAC and MAC, respectively). Thermal envelope qualities, hydronic systems, radiator types, and PV are included in each Test Case. Test Case C follows a trend similar to B and Test Case D follows a trend similar to A. As already mentioned above, this can be explained by the ratio between envelope and treated floor area. As observed for Test Case A, the B/W HP allows for higher CO_2 savings at a similar total annual cost and a similar cost per unit of CO_2 saved, compared to the A/W HP. However, application may be limited to locations where boreholes can be drilled and due to the higher investment costs financing can be more challenging. Test Case D, the large detached building, is the only case with several economically favourable solutions.

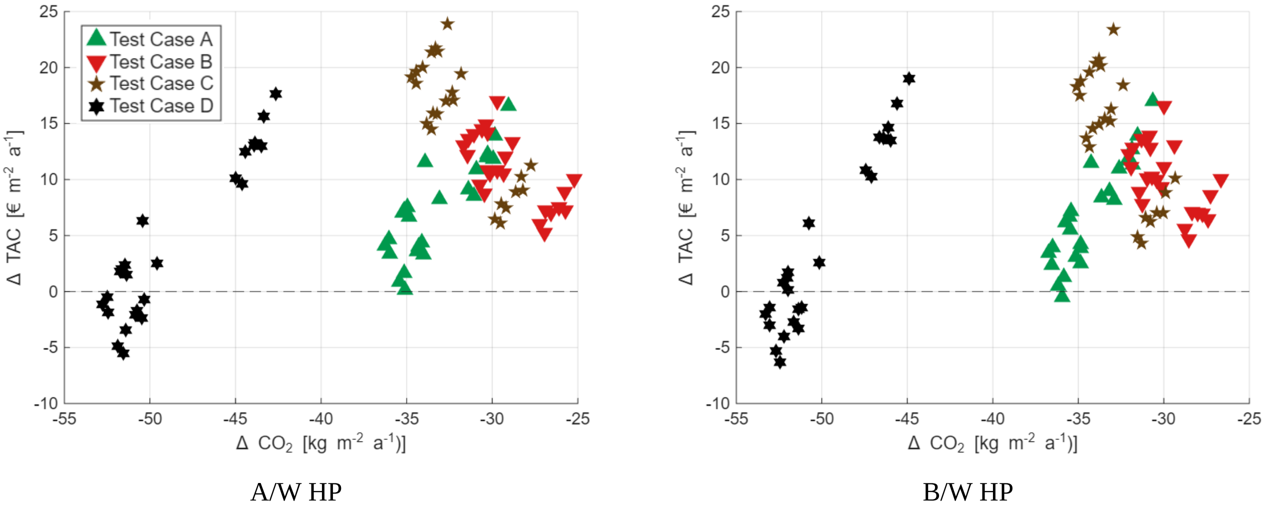


Fig. 9: Additional total annual costs vs. additional CO_2 emissions compared to the reference case for all Test Cases. Each point represents a different combination of thermal renovation level, hydronic system, radiator, and PV installation

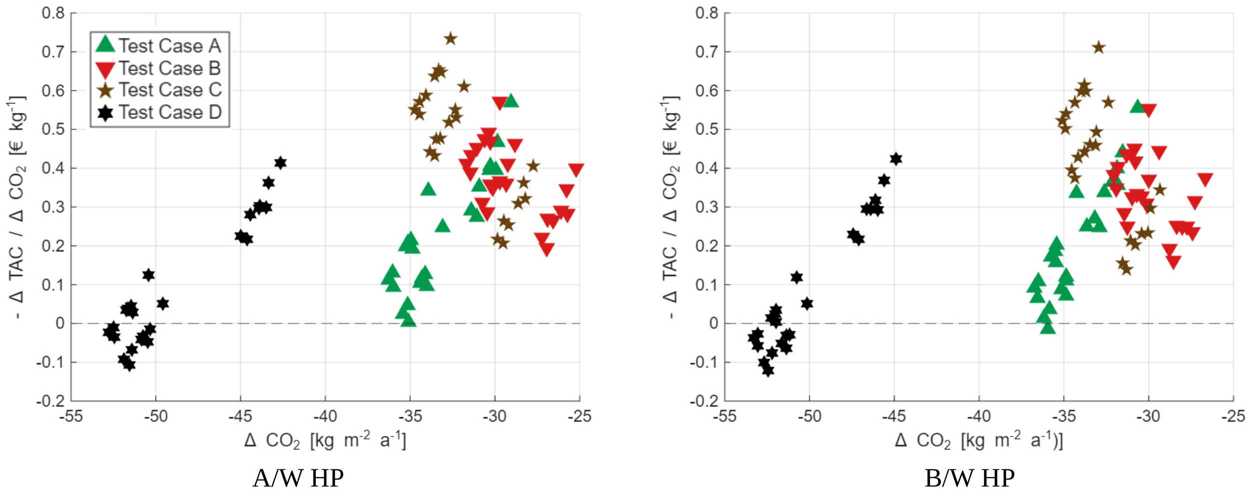


Fig. 10: Marginal abatement costs vs. additional CO_2 emissions compared to the reference case for all Test Cases. Each point represents a different combination of thermal renovation level, hydronic system, radiator, and PV installation

These differences between the buildings show that results are case-specific, which confirms the need for a simplified integral planning tool to explore different technology combinations at the early design stage of a project. Such a tool cannot replace detailed dynamic building and HVAC simulations, but it enables a selection of solutions and exclusion of suboptimal solutions. Contrariwise, detailed dynamic simulations could not be performed at an early design stage for all combinations. Selected dynamic simulations will be performed, and results will be used in a validation process. However, it is noteworthy that the results are subject to uncertainty and strongly depend on the assumptions, in particular regarding costs. Hence, these results are rather suitable to observe trends than to find the absolute optimum. Thus, the purpose of this contribution is to present the integral planning workflow rather than to give a recommendation for a specific variant.

Different renovation scenarios also lead to different installed electric power requirements for the heat pump and electric boiler, as presented in Fig. 11 for Test Case A. This is important because even when the resulting energy consumption is comparatively small, the required installed power can still be high (as in the case of no renovation combined with heat pump installation). This has direct implications for grid capacity and peak load, which are not necessarily reflected in annual energy figures alone.

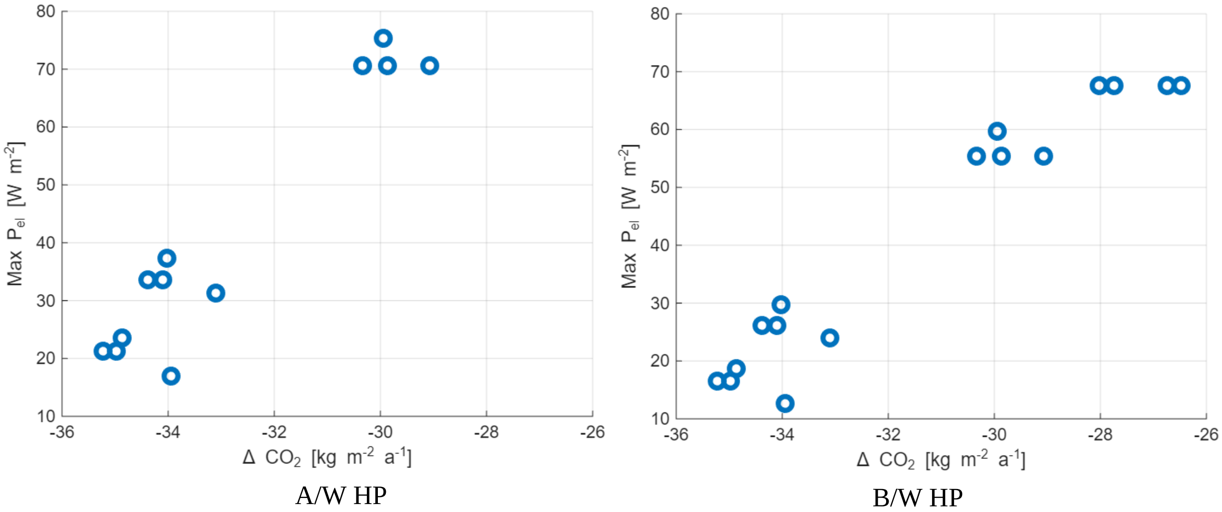


Fig. 11: Maximum electric power installed (HP and electric boiler when present) vs. additional CO_2 emissions compared to the reference case for Test Case A (cases without PV)

4. Conclusions

This study presented a spreadsheet-based integral planning approach to perform a techno-economic analysis of HP system solutions for MABs, considering different renovation levels, hydronic system configurations, radiator configurations, and including on-site renewable energy generation. The analysis is carried out for four representative buildings, using a monthly resolution to capture seasonal effects such as the PV self-consumption and the seasonally varying electricity mix.

The results highlight the need for an integral planning workflow and integral planning tools, as the techno-economic optimal solution is case- and site-specific and general conclusions cannot be easily derived. This type of analysis needs to be carried out at the early design stage of a project, when a very detailed analysis is not possible: therefore, a simplified approach, such as the one presented in this study, is required.

As typical for such optimization problems, the results form a Pareto front, from which a solution can be chosen depending on the specific targets (such as minimal TAC or minimal CO_2 emissions). The shape of the Pareto front varies between the Test Cases. In Test Cases B and C for example, reaching an economically feasible solution is more challenging, and additional renovation variants should be included. In all cases PV leads to CO_2 and total costs saving, but it requires higher initial costs. The choice of an electric boiler for DHW preparation can offset the benefits of the thermal renovation: thermal renovations combined with a two-pipe HP-based system for space heating and an electric boiler for DHW is disadvantageous compared to a minimal renovation with a HP system for SH and DHW.

Results would change with a feed-in tariff for electricity delivered to the grid. Scenarios for the future development of the electricity mix and time (i.e. seasonally) depending on electricity prices should be considered in future work. Furthermore, it would be important to consider further HP system concepts such as the booster-HP system. Further details and results will be provided in Deliverable 4.2 of the KnowHowHP project.

Additionally, and maybe most importantly, the choice of a renovation level and of a HP system topology influences thermal and electric peak power requirements. This affects the required HP size, with implications for installation space and sound emissions, as well as the required grid connection, with implications for grid stress and, in future, potential peak power costs.

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